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CHARGE ASYMMETRY IN $\mu^{\pm}$N DEEP INELASTIC SCATTERING

BCDMS Collaboration

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1. INTRODUCTION

The discovery of neutral currents in νN interactions[1] in 1973 triggered both experimental and theoretical effort to study in detail their structure. The experiments done since then on νN, νe, eN, and e^+e^- scattering are in a good agreement with the prediction of WS-GIM standard model [2] which describes the amount of mixing between SU(2) and U(1) gauge bosons in terms of a single free parameter $\sin^2\theta_w$. Since the WS-GIM model seems to be the strongest candidate for the correct theory of weak and electromagnetic interactions it is considered important[3,4] to test the model in new kinematical regions and reaction channels.

The Bologna-CERN-Dubna-Munich-Saclay collaboration (CERN NA4 experiment) made a measurement of deep inelastic scattering of muons on nucleons

$$\mu^{\pm}N \rightarrow \mu^{\pm} + \dots$$

at two energies 120 and 200 GeV using an isoscalar target (carbon) in order to measure the effect of the Z^0 exchange interfering with the dominant one photon exchange and check the prediction of the WS-GIM model. This experiment differs from the SLAC e^-D experiment[5] in that both the helicity and the charge of the muon are simultaneously reversed, i.e. we measure the charge conjugation asymmetry B (z, λ) defined as

$$B(z,\lambda) = \frac{\frac{d\sigma^+(-\lambda)}{dz} - \frac{d\sigma^-(\lambda)}{dz}}{\frac{d\sigma^+(-\lambda)}{dz} + \frac{d\sigma^-(\lambda)}{dz}}, \qquad (1)$$

where z is a convenient kinematical variable and λ is the average longitudinal polarization of the muon beam. To measure B(z, λ) the polarity of all magnets in the experiment (both beam transport and spectrometer) have to be simultaneously switched back and forth. Taking into account only one photon and one Z^0 exchange graphs the asymmetry B(z,λ) is equal to[6]

$$B(z,\lambda) = -K(a_\mu - \lambda v_\mu)A_0 z, \qquad (2)$$

where $K = \frac{G}{\sqrt{2}} \cdot \frac{1}{2\pi\alpha} = 1.8 \cdot 10^{-4}$ GeV^{-2} determines the strength of γZ^0 interference, $a_\mu (v_\mu)$ is the axial-vector (vector) neutral coupling of a muon to the Z^0 and $z = g(y)Q^2 = \frac{1-(1-y)^2}{1+(1-y)^2}\, Q^2$, $y = 1 - \frac{E'}{E_0}$, $E'(E_0)$ being the energy of the scattered (incident) muon. In the framework of the parton model the ratio of structure functions A_0 for isoscalar target reduces to a constant

$$A_0 = \frac{xG_3(x,Q^2)}{F_2(x,Q^2)} = \frac{6}{5}\ (a_d - 2a_u),$$

where a_q is the axial-vector coupling of a quark to the Z^0.

It has been shown[7,8] that higher order electromagnetic and weak terms make an important contribution to the B asymmetry and tend to decrease it (e.g. by ∿ 40% at an incident energy 200 GeV).

2. APPARATUS

The general layout of the NA4 spectrometer is shown in fig. 1. It consists of a 50 m long torus of iron magnetized to saturation with targets located in the central hole. Muons of the same charge as the incident beam are focused by the magnetic field and perform periodical oscillations inside the iron (fig. 2). The spectrometer is subdivided into ten identical supermodules. Each supermodule (fig. 3) consists of:

(a) a separate carbon target 5 m long except in the last two supermodules,
(b) magnetized iron and coil;
(c) two trigger counters and eight multiwire proportional chambers to determine the muon trajectory inside the iron.

A set of three beam hodoscopes with a mosaic structure is used to correlate the beam muon which initiated the trigger with hits in the momentum defining hodoscopes installed in the beam line on both sides of a set of deflecting magnets (BMS). The first of the beam hodoscopes monitors the beam flux and is also used in the trigger logic. The apparatus is shielded against the beam halo muons by a veto system of scintillation counters.

The trigger enables to detect interactions wherever they occur along the effective target length of ca. 36 m. The standard trigger condition for data

constant nominal bending angle and bending power of the deflecting magnets), scattered muon momentum p, four momentum transfer Q^2, yield = number of events/incoming flux ,etc. Typical time stability plots for accepted events are shown in figs. 4 and 5 for one of the periods at 200 GeV. Each point represents approximately 4000 events.

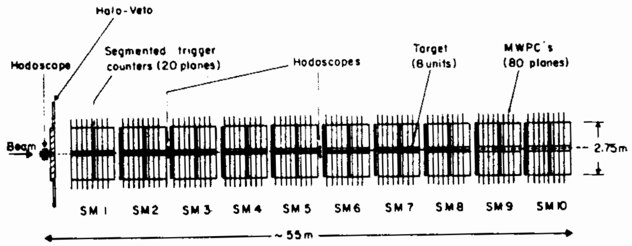


Fig. 1. Schematic view of the NA4 spectrometer.

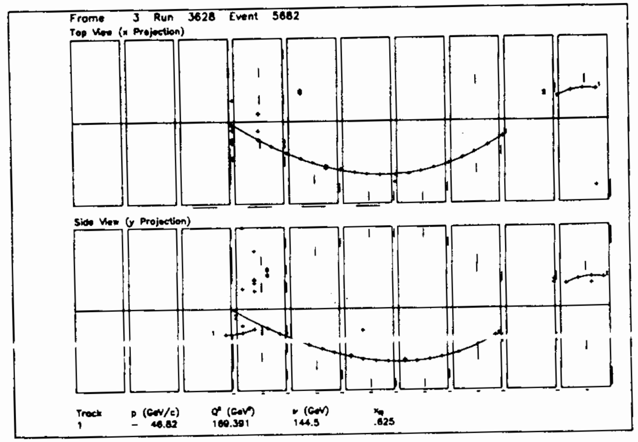


Fig. 2. Computer reconstruction of a typical deep inelastic event in the spectrometer.

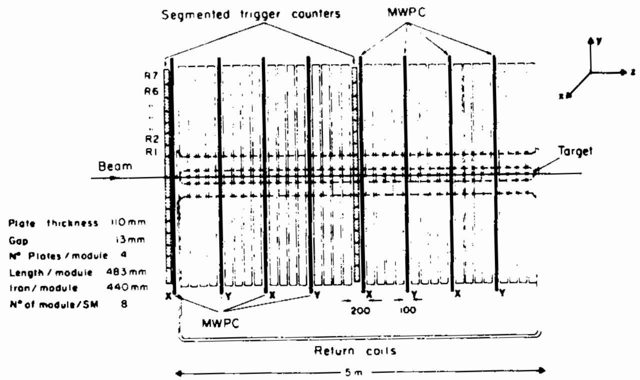


Fig. 3. Structure of one supermodule.

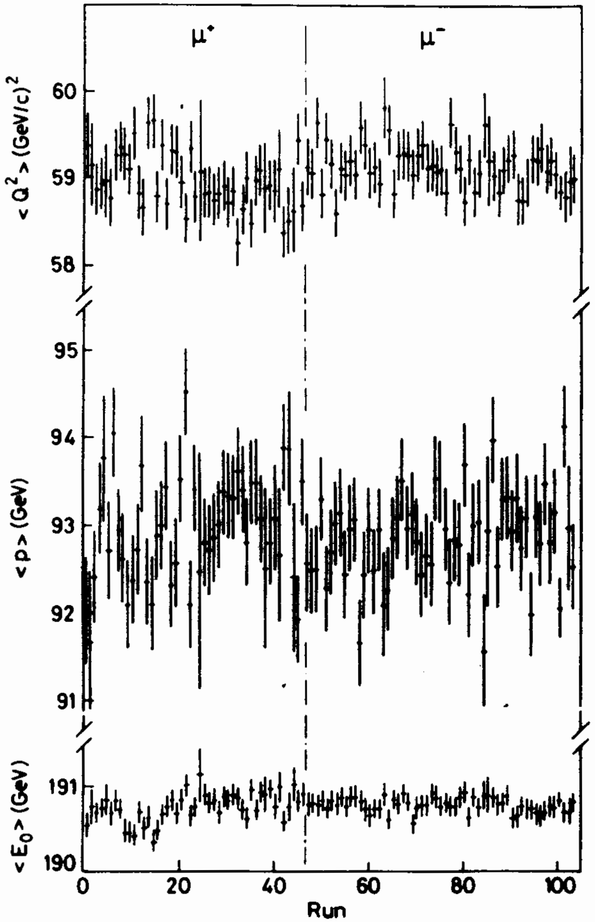


Fig. 4. Time stability of the mean values of E_0, p, Q^2.

The comparison of μ^+ and μ^- data was done in terms of the asymmetry B (see (1)) taking instead of z geometrical variables such as v_z (vertex positions), ϕ (azimuthal angle of the scattered muon) and many others. All distributions show a very good compatibility with zero (lower part of figs. 6,7) within the errors. The asymmetry B as a function of Q^2 is shown in the lower part of figs. 8,9 for energies 120 and 200 GeV respectively.

In fig. 10 the asymmetry B for the 200 GeV data is plotted as a function of Q^2, p (momentum of the scattered muon), x and z = $g(y)Q^2$ after cuts:

$0.11 < Q^2/Q^2_{max} < 0.375$

$0.2 < y < 0.9$

$0.2 < x$

$700 < v_z < 3100$ cm .

The cuts remove that part of the kinematical region where the acceptance is rapidly varying. It has been checked that these or other cuts do not change the resulting B by more than one standard deviation. The solid lines in fig. 10 represent linear fits to data not corrected for higher order radiative effects.

Linear fits to the Monte-Carlo prediction for B asymmetry including radiative effects in different variables are shown in fig. 10 by dashed lines. The general trends of data and Monte-Carlo are the same; the shift between data and Monte-Carlo of about $4 \cdot 10^{-3}$ is possibly due to a systematic error in the relative normalization between μ^+ and μ^- data.

The asymmetry B(z) shown in fig. 11 has been corrected for higher order electromagnetic processes. Fitting the two data samples independently the following values for the slope b of the B asymmetry are obtained:

$b = -(1.67 \pm 0.45) \cdot 10^{-4}$ GeV^{-2} at 200 GeV and

$b = -(1.7 \pm 1.1) \cdot 10^{-4}$ GeV^{-2} at 120 GeV.

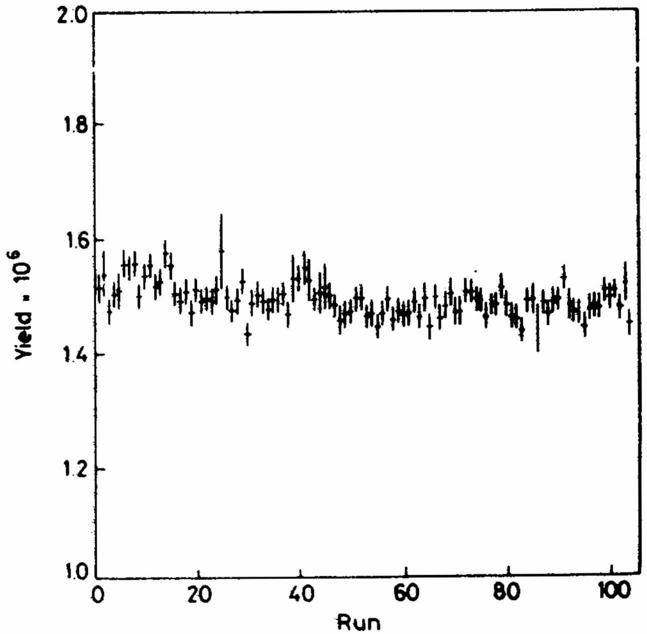


Fig. 5. Time stability of the mean value of the event yield.

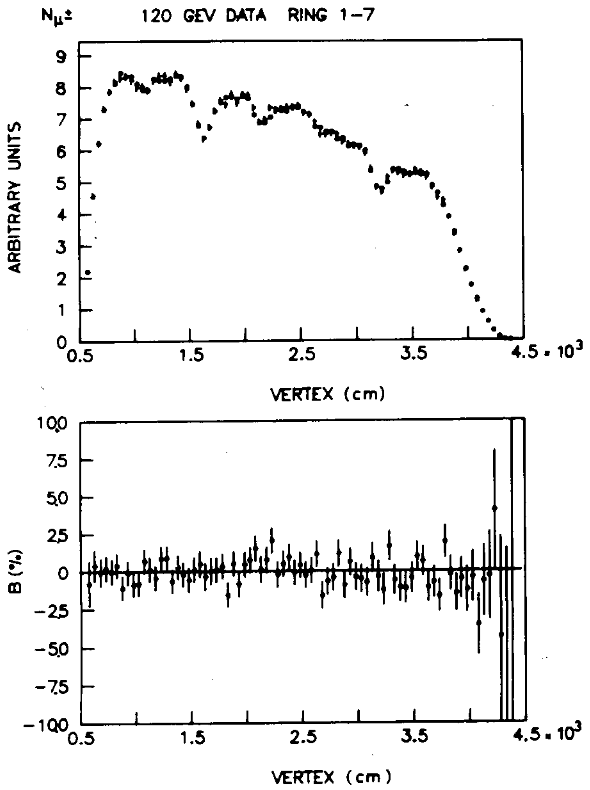


Fig. 6. Distribution of $\mu^\pm$ events (upper part) and the asymmetry $(d\sigma^+ - d\sigma^-)/(d\sigma^+ + d\sigma^-)$ (lower part) as a function of the vertex position in the spectrometer at 120 GeV.

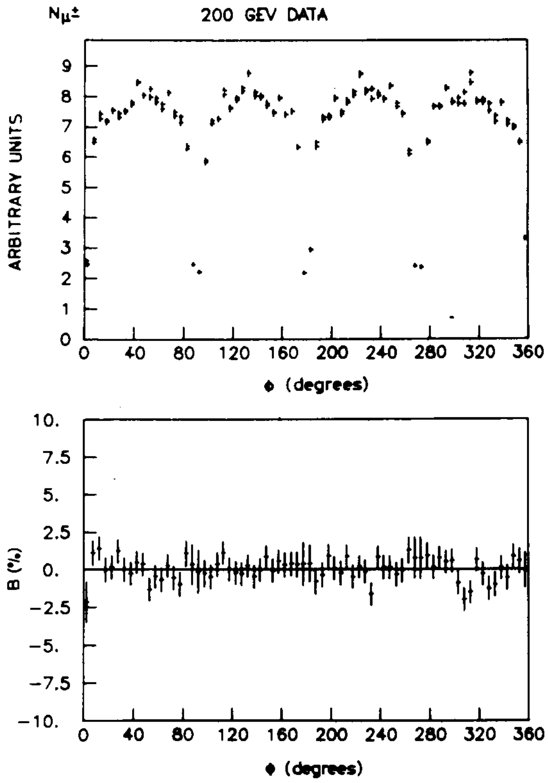


Fig. 7. Distribution of $\mu^\pm$ events (upper part) and the asymmetry (lower part) as a function of the azimuthal angle ϕ at 200 GeV.

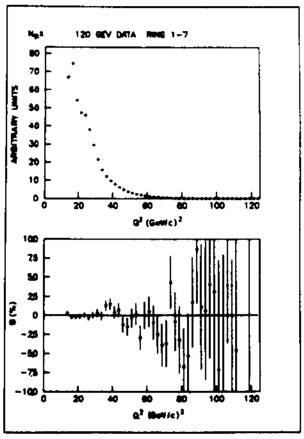


Fig.8. Distribution of $\mu^\pm$-events (upper part) and the asymmetry (lower part) as a function of Q^2 at 120 GeV.

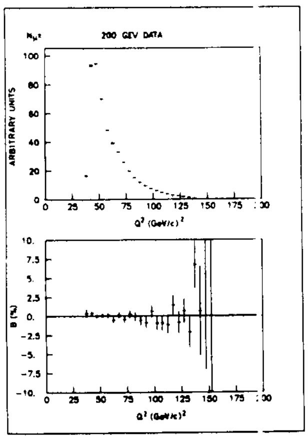


Fig.9. Distribution of $\mu^\pm$ -events (upper part) and the asymmetry (lower part) as a function of Q^2 at 200 GeV.

Fig.10. The B asymmetry as a function of Q^2, p, x and $z = g(y)Q^2$ at 200 GeV. Solid lines represent linear fits to data. Dashed lines are for Monte-Carlo prediction.

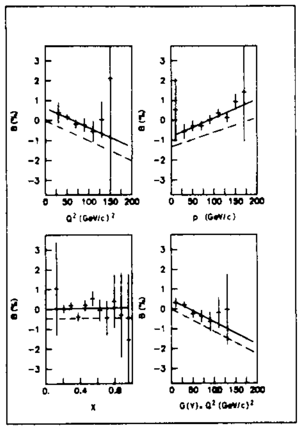
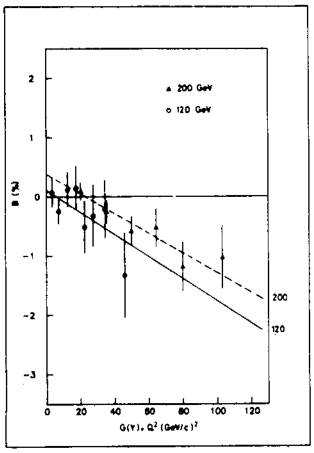


Fig.11. The B asymmetry as a function of z at 200 GeV (Δ) and 120 GeV (o) after radiative corrections. The solid (dashed) line is a linear fit $B(z) = a + bz$ for 120(200)GeV data.



taking required the coincidence of four consecutive trigger planes (∿ 11 m long track) and the beam • $\overline{\text{halo}}$ signal. The construction of the segmented trigger counters makes it possible to require a minimum Q^2/Q^2_{max} of scattered muons. Most of the data were taken with the condition $Q^2/Q^2_{max} > 0.1$. The detailed description of the spectrometer is being published elsewhere[9].

3. PRELIMINARY RESULT ON ASYMMETRY

Data for the B asymmetry were taken at two energies 200 and 120 GeV at fixed beam intensity of about 2.10^7 μ/spill in eight data taking periods of 12 days each. Usually during a period the beam charge was reversed twice in order to reduce time dependent systematic effects.

At 200 GeV the sequence of measurements was the following:

|+ − +|− + −|+ − +|− + −|− +|

with the requirement $Q^2 \geq 40$ GeV². At 120 GeV two different trigger conditions were applied:

- $Q^2 \geq 20$ GeV² with polarity switches |+ − + −|+ − +| and
- $Q^2 \geq 12$ GeV² with polarity switches |+ − +|.

The data sample presented contains the following number of events:

μ^+	μ^-	beam energy
$4.7 \cdot 10^5$	$6.5 \cdot 10^5$	200 GeV
$4.6 \cdot 10^5$	$4.8 \cdot 10^5$	120 GeV

which represent 70% of the available statistics at both energies. In the current analysis the main emphasis has been put on checking the time stability of the data and to search for possible systematic effects. About 15% of the data has been rejected at this stage of analysis because it did not meet stability criteria concerning mean values of different quantities such as detector efficiencies, incoming energy E_0 (as determined by the BMS assuming a

Within the framework of the Weinberg-Salam-GIM theory one can write

$$\sin^2\theta_W = \frac{1}{4} + \frac{1}{4|\lambda|}\left\{\frac{-2b\cdot 10^4}{3.22} - 1\right\},$$

where $|\lambda|$ is the average polarization of the μ beam. With $|\lambda| = 0.75$[10]: we obtain

$\sin^2\theta_W = 0.26 \pm 0.09$ at 200 GeV and
$\sin^2\theta_W = 0.27 \pm 0.22$ at 120 GeV.

Our result can be compared with the value of 0.224 ± 0.020 obtained in the SLAC eD experiment[5] or the value of 0.26 ± 0.06 from PETRA experiments[11].

Assuming a general SU(2) x U(1) gauge theory our data can set a limit on the weak isospin of the right handed muon[12] since

$$b/-KA_0 = a_\mu - \lambda v_\mu = I_3^L(\lambda-1) + I_3^R(\lambda+1) + 2\lambda\sin^2\theta_W.$$

Taking the world average for $\sin^2\theta_W = 0.23$ and assuming $I_3^L = -1/2$ we obtain:

$I_3^R = 0.03 \pm 0.08$ at 200 GeV and
$I_3^R = 0.03 \pm 0.19$ at 120 GeV,

confirming that the right handed μ is a singlet.

4. SYSTEMATIC ERRORS

The study of systematic errors is in progress. Here we briefly mention some possible sources of systematic errors:

4.1 Spectrometer

(a) Its magnetic field was kept on a given hysteresis loop using a computer program. During data taking the temperature of the iron was monitored and two Hall probes measured the magnetic field inside the iron. As indicated by the Hall probes, the reproducibility and reversibility of the field was better than $4\cdot 10^{-4}$ of its absolute value. A Monte-Carlo calculation shows that the ensuing error on the slope B is limited to less than $2\cdot 10^{-5}$.

(b) The difference $\epsilon^+ - \epsilon^-$ between detector efficiencies for μ^+ and μ^- data is smaller than $2\cdot 10^{-3}$ for most detectors (MWPCs, trigger counters, trigger stations). The large redundancy of our spectrometer (e.g., the mean number of points in the MWPC per track is 28) enables us to evaluate efficiencies with a high accuracy and makes the data less sensitive to the malfunctioning of a single detector. The asymmetry due to efficiency differences calculated by Monte-Carlo for one third of the statistics is less than $2\cdot 10^{-3}$.

(c) Showers and δ rays: we observe a small excess (2.5%) of extra hits in MWPCs for μ^+ data. They can influence the resolution and generate small asymmetries. However, a preliminary Monte-Carlo investigation shows that the effect on the B asymmetry is negligible.

4.2 Beam

(a) The bending power of the deflecting magnets in the BMS was monitored by Hall probes. The present limit on the reproducibility and reversibility of the bending power is $2 \cdot 10^{-3}$. Auxiliary measurements and analysis should further reduce this source of error which mainly influences the asymmetry B at small z-values.

(b) The beam divergence increases with the radius and reaches 0.4 mrad at r = 2cm (FWHM of the beam profile). A study done on a part of the data shows that the relative difference in the mean beam angle and in the beam divergence between μ^+ and μ^- is compatible with zero. We also do not see any asymmetry between μ^+ and μ^- data as a function of the vertex position. Therefore, the beam divergence is not expected to cause any significant systematic error of B.

4.3 Contamination

(a) No clear signal of residual halo was found in the data. The scanning done on a part of data shows that the halo contamination is less than 10^{-3}.

(b) The contamination from decays of hadrons in our data is less than $5 \cdot 10^{-4}$ and is not expected to exhibit a large asymmetry.

The slopes of the B(z) asymmetry are compatible within 1σ in four different periods at 200 GeV (see fig. 12a). When dividing data of the same beam polarity into two halves in each period and fitting them in the same way as the μ^+ μ^- data we obtain slopes compatible with zero (see fig. 12b) except one point which is 3.4σ off the zero line.

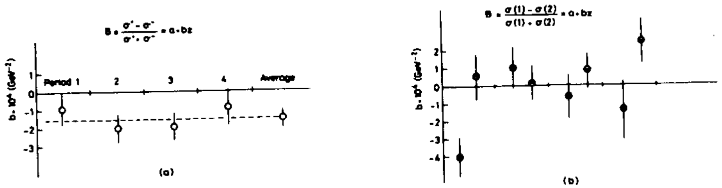


Fig. 12. (a) Slopes b for four measurements of B asymmetry at 200 GeV (data corrected for rad. corr.).

(b) Slopes b of the asymmetry in the same charge comparison. σ(1) and σ(2) are the first and the second part of data of the same charge within one period.

5. CONCLUSIONS

The preliminary result on deep inelastic scattering of μ^+ and μ^- off a carbon target at 120 and 200 GeV shows a negative "charge conjugation asymmetry" B(z). The data are in agreement with the standard WS-GIM electroweak model and give a value of $\sin^2\theta_W = 0.26 \pm 0.09$. The data also set a stringent limit on the weak isospin of the right handed muon:

$$I_3^R = 0.03 \pm 0.08,$$

which proves the muon to be a right handed singlet. The errors are statistical only. Although no obvious systematic effects are found, the full evaluation of systematic errors is not yet completed .

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Ардженто А. и др. E1-82-479
Зарядовая асимметрия в глубоконеупругом $\mu^{\pm}N$-рассеянии

Сотрудничеством БЦДМС /эксперимент НА-4 в ЦЕРНе/ получены данные для измерения асимметрии в глубоконеупругом рассеянии пучков μ^+ и μ^- на углеродной мишени. Этот эксперимент позволяет проверить структуру нейтрального слабого тока и определить предел по слабому изоспину для правовинтового мюона.

В стадии анализа находятся $2,5\cdot10^6$ событий, зарегистрированных при энергиях 120 и 200 ГэВ. Изучение систематических ошибок еще не закончено. На современном уровне понимания данных наблюдается согласие со стандартной моделью ВС-ГИМ.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна 1982

Argento et al. E1-82-479
Charge Asymmetry in $\mu^{\pm}N$ Deep Inelastic Scattering

The BCDMS Collaboration (CERN NA4 experiment) has taken data to measure the asymmetry in the deep inelastic scattering of μ^+ and μ^- beams incident on a carbon target. This measurement can check the structure of the neutral weak current and set a limit on the weak isospin of the right-handed muon. The analysis of 2.5 million events taken at 120 and 200 GeV is in progress. The study of systematic errors is not yet fully completed. At the present level of understanding the data are in agreement with the standard WS-GIM model.

The investigation has been performed at the Laboratory of High Energy Physics, JINR.

Preprint of the Joint Institute for Nuclear Research. Dubna 1982